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Sustainable Agriculture Technical Note

Affordable Opportunities For Precision Farming

A practical way to support sustainable agriculture

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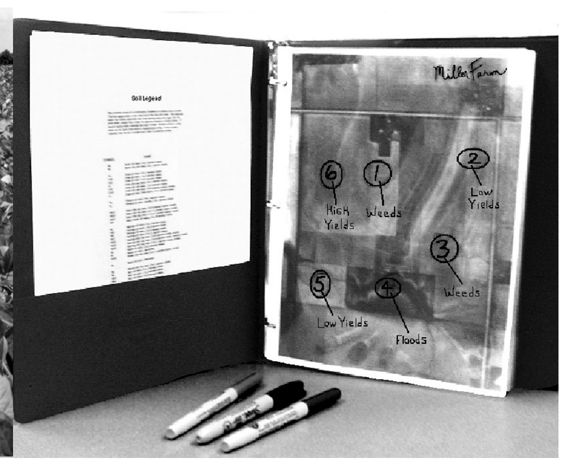

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Purpose

Sustainable agriculture involves the use of innovative technologies to produce food and fiber in farming systems that are ecologically, economically, and socially beneficial. The purposes of this technical note are to provide a brief background on precision farming and to describe ways in which its concepts and principles may be applied on farms without a substantial investment in equipment. This information is intended to help farmers who may or may not own a computer, but who are interested in long-term management strategies for improving their farm.

What is Precision Agriculture?

Precision agriculture is a strategy of managing small areas within fields instead of managing whole fields as a single unit. Many farmers have documented the value of using site-specific information to manage pests, nutrients, seeding rates, water, and other resources more efficiently.

Typically, precision farming is associated with sophisticated computer and satellite technologies, which some farmers have neither the physical nor the financial resources to implement. However, even without expensive technologies, precision farming may be used to enhance a wide variety of crop management decisions. A few examples are provided here, but there are others. Any farming practice that can be managed spatially (i.e., across different geographic areas) or temporally (over time) can be improved with precision farming. Examples of management that may benefit from precision farming follow:

Soil Fertility and Soil Quality. Yield levels within a field may be correlated with soil nutrient levels. Decisions regarding fertilizer rates, where to apply lime, and where and how much manure to apply may be based on this information. Information about topsoil depth, organic matter, and traffic patterns can be used to help manage compaction, drainage, water holding capacity, erosion, and buffer strips.

Pest Management. Scouting for pests can be used in sections of fields in the same way it has been applied to whole fields. Insects, diseases, and weed infestations tend to be clustered together in patches. Basic information technologies can help determine where these infestations occur or are most likely to occur. Farmers may then make decisions regarding site-specific treatment that can save money and reduce the risk of water contamination from a widespread application of pesticides.

Planting Decisions. Variety choice, seeding rate, and seeding date decisions may benefit from site-specific information. On sandy soil or south-facing slopes, drought-tolerant varieties may be needed. On saline soils, salt-tolerant plants may be needed. In cooler areas, such as on north-facing slopes, seeding dates may be delayed and seeding rates may be increased to maximize yield potential and minimize the potential for crop failure.

Enterprise Placement. Enterprises must be located only on suitable sites. Knowing the spatial characteristics of the farm can help farmers determine where individual enterprises are most appropriate.

The Costs and Benefits of Precision Farming

Precision agriculture is usually associated with sophisticated technologies that vary in price. The common technologies associated with precision farming include computer hardware and software, GPS and yield monitoring equipment, and equipment for variable rate applications. The cost for these technologies may range from several thousands of dollars to tens-of-thousands of dollars, plus $10+ per acre for an initial soil grid soil sampling with a 2.5-acre grid size. Annual fees for weather information, variable-rate application, and related services may cost as much as $12 per acre.

Despite these costs, precision farming can sometimes pay off if it results in more efficient use of resources and inputs. When a whole field is treated uniformly, some areas will receive excessive amounts of fertilizer or pesticides that will not result in higher yields. Other areas will not receive enough inputs. Or perhaps spot treating a pest infestation or deep ripping a small portion of a field will generate a greater yield and income benefit than if the same amount of money were put into a different input spread across the whole field. ***The goal of precision agriculture is to gather site-specific information and enable farmers to vary management practices more appropriately within fields.*** These principles of precision agriculture are relevant to small and large farms and to high-tech and low-tech approaches to gathering information.

Spatial Variability

Why does land vary?

No field is uniform. Soils, historic use, microclimate, and pest pressures can vary significantly over short distances. Variability can be caused by geologic, topographic, atmospheric, and human factors. Knowing sources and kinds of variability can help farmers recognize these differences and manage for them.

As landscapes were shaped over geological time, spatial variability emerged as a natural part of soil formation (fig. 1). Parent materials (the rocks, minerals, and organic material from which soils developed) differed from place to place and from time to time; erosion and deposition rearranged the depth of soil across the landscape. Low-lying areas gained topsoil and nutrients from surrounding land; higher ground may have been stripped of nutrients through erosion and leaching.

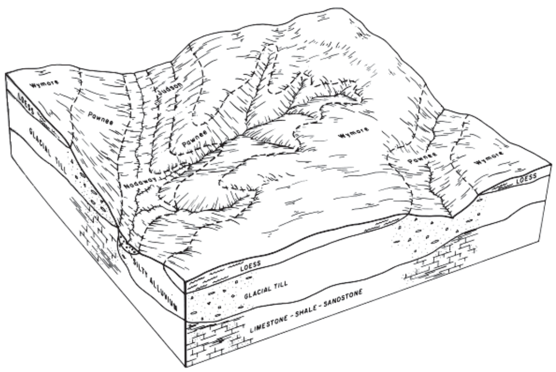


Figure 1. Differences in geologic parent materials and landscape position cause soils with different characteristics to form over time.

Changes in agricultural land use have also created spatial variability. Animal enclosures—a frequent part of farming before tractor mechanization—created areas of nutrient deposition. Many wood lots, pastures, windbreaks, and fence lines, common at the turn of the twentieth century, have been removed, leaving variations in the soil resource.

In a few years, or even within a year, weeds and pests can create their own spatial variability and problems. The dispersal of seed or the spreading of perennial weeds by underground shoots can lead to clumps of weeds near invading plants. Windborne insects and pathogens may infest a crop in a random pattern. Some areas of a field may be severely damaged, while other areas remain unaffected.

Farmers also cause spatial variability. Tractor tires can create compacted areas, especially in turn-rows. Inconsistent maintenance of spray nozzles and injector knives can cause row-to-row variability in crop vigor due to the differences in application rates. Broadcast amendments often have strips with double the application rate, where the application path overlaps, or no amendments at all, where the applicator misses the target. So, nothing in the real world of agriculture is uniform.

Scale of Variability

The scale of variability is the distance over which conditions change. For example, patches of weeds may cover an acre, while nutrient levels may differ over distances of inches under a history of banded fertilizer applications. The scale of variability determines the opportunities to manage the variation. If conditions vary little within fields (i.e., the scale of variation is quite large), fields can be sampled and managed as single units. No new technology is needed. Precision farming technology is also not needed if the scale of variation is quite small because it is not practical to manage small sites differently.

Each problem has its own scale of variability so different **management zones** should be developed for each problem. A flood-prone section may form a single large zone in the lower part of a field, but spots of sandy, eroded, compacted, or high pH soils may need fine-scale management targeted to areas of less than an acre.

When is it Worthwhile to Implement Precision Farming?

The value of site-specific management, both in determining and solving problems, depends on the nature of the spatial variability. When assessing whether spatial variability justifies the investment of time and money required to implement precision farming, it is helpful to break the problem into some separate questions:

1. What are the extremes? If all of the soil test values are above the critical threshold for adding fertilizer, then it does not matter how much spatial variation there is — no fertilizer should be applied to the field.

2. Is the variability observed in large patches? If it is not observed in large patches, then it may be impractical to vary management over the small distances that the changes occur.

3. How skewed (lopsided) is the variability? Most soil properties are skewed. That is, very few places within a field match the average measured for the field, and some places may be much higher or lower than the average. When a field is highly skewed, managing for the **average** situation is most likely to have poor results because most of the field will not be close to the average (fig.2). Implementing precision farming can be cost effective in these situations.

4. Does crop productivity vary in a gradual manner from one part of the field to another, or are there sharp boundaries of differing yields? For example, does yield increase (or decrease) gradually from the top to the bottom of a slope, or does it abruptly increase or decrease at some point? Yield patterns may give clues about the reasons they occur and may be helpful in establishing management zones.

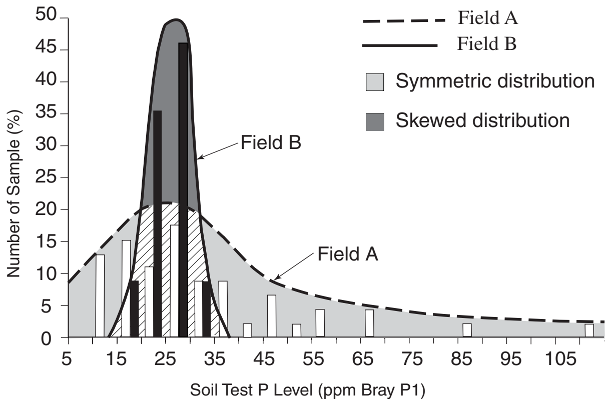


Figure 2. Results of a study in which 45 soil samples from each of 2 fields were analyzed for available phosphorus. Field A (light colored bars) had a higher average test level than Field B (dark colored bars). Neither field would appear to need P fertilizer based on the averages. However, the variability in Field A is skewed. A few very high values have raised the average test level in that field. In reality, 13 percent of Field A has values of 10 ppm or less. Those areas are likely to show a profitable response to additional manure or fertilizer.

A Low Cost Record Keeping Method

By combining existing maps with maps of farmer observations, measurements, and management practices, farmers can learn about patterns and causes of variability on their land. The goal of precision farming technology is to improve the efficiency of gathering measurements, combine them into informative maps, and vary management practices based on the more detailed information. This section describes a low-cost spatial record keeping procedure that does not require a computer. Using the process described here may help anyone manage their farm resources more efficiently, meeting production levels while reducing costs, inputs, and negative off-site effects — all goals of sustainable agriculture.

The Method

Materials needed for this procedure include:

- *County soil survey* provides soil maps and land use interpretations of the farm to be mapped. Soil surveys may be obtained from the local county Natural Resources Conservation Service (NRCS) office, Cooperative Extension Service, Soil and Water Conservation District office, or possibly a local library. Information available in the soil survey includes soil descriptions, land use suitability and/or limitations, and types and locations of other soils that may be in the vicinity.
- *Aerial photograph* of the farm may be obtained through the local NRCS or Farm Services Agency (FSA) offices, or may be downloaded from the Internet.
- *Clear transparency sheets* or other see-through, standard letter-sized sheets are available at office or art supply stores.
- *Permanent transparency markers* or other felt-tip markers are generally available wherever school supplies are sold.
- *Farm data and records*, such as soil testing information, precipitation and other weather data, historical land use records, and recent management practices.
- *A three-ring binder* or other book to organize and protect the spatial record keeping kit (fig. 3).

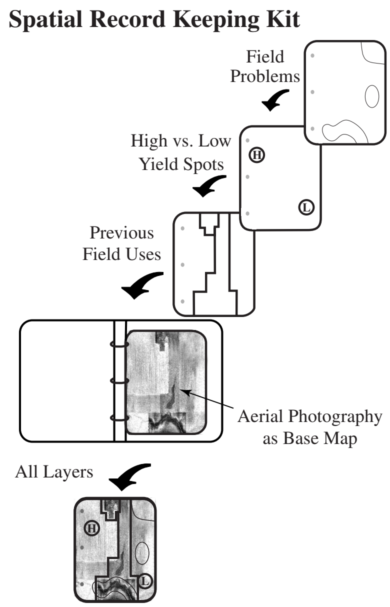


Figure 3. The spatial record keeping kit can help the farmer keep track of on-farm variability and how it changes over space and time.

Step 1. Obtain a base map
This map will be the background for all the transparent overlays. See the section below for suggestions of sources of maps. A soil survey map is recommended because it contains soil mapping unit lines superimposed on an aerial photograph. Photocopy the pages of the soil survey that contain the farm. Enlarging the soil map on a copy machine makes it easier to view. If an aerial photograph or digital orthophotograph is used as the base map, record soils information on a separate overlay transparency.

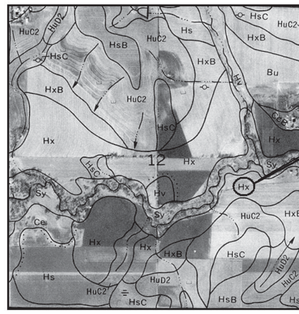
Step 2. Create an outline map
This map will be a simple line drawing of the boundaries and major landmarks on the farm. Lay a transparent sheet of plastic over the base map and use a permanent marker to trace the boundaries of fields, roads, streams, farmsteads, and other landscape features to use as reference points. By making copies of this on paper or plastic transparencies, the outline can be used as a base for recording other information.

Step 3. Record soil information
Whether a soils map is used as a base or an overlay, read and record notes about the characteristics of the soil mapping units on the farm. Mapping units may be designated with numbers or a combination of letters and numbers (fig. 4). The soil survey provides a detailed description of each mapping unit. Record information from the soil survey about the soil texture of the A and B horizons, slope class, and management characteristics, such as drainage class, stoniness, and water holding capacity. The soil survey also has useful interpretive ratings for water management, irrigation potential, and other land uses. Employees at the local NRCS office can help clarify symbols used in the soil survey and identify soils with unlike properties that may warrant individual treatment. Traditional soil surveys are called Order 2 surveys, meaning that each mapping unit is actually a mix of different soils. If yield varies significantly across a field, but the soil survey indicates that only one type of soil is present, the variation may be due to soil inclusions. A soil scientist may be able to explain at least some of the differences observed.

Step 4. Create overlay maps
Draw a series of overlay maps that can be stacked to identify similarities in patterns. Each transparent overlay should show only one type of information and should be labeled with the topic, date, and time of observation. They must be drawn on the same outline map or show the same landmarks so they can be lined up and compared. Use a different pen color or line pattern for each sheet so each piece of information can be differentiated when several transparencies are stacked together.

Maps of some information, such as land use history and topography, need only be drawn once. Other information, such as weed patterns or ease of tillage, can be drawn at regular intervals to track changes in these properties. Overlays may show information, such as:

- Topography (high spots, low spots, and/or steep areas)
- Weeds (type of weeds present and size of patches)
- Yields (areas of noticeably higher or lower yields, or actual yield measurements)
- Crop growth characteristics (leaf color, stunting, disease)
- Insect damage and type of insect
- Soil moisture observations (droughtiness, ponding after rain)
- Ease of tillage
- Soil color
- Drainage patterns
- Erosion



A Section from York County, NE

Map Symbol	Mapping Unit
HwC	Holder silt loam, 3 to 6 percent slopes.
Hx	Hord silt loam, terrace, 0 to 1 percent slopes
HxB	Hord silt loam, terrace, 1 to 3 percent slopes
HyC	Hord complex, 3 to 6 percent slopes
Ma	Marsh
Sc	Scott silt loam, 0 to 1 percent slopes
Sy	Silty alluvium land

Figure 4. Soil mapping units are delineated on soil survey maps and described in the soil survey.

- Earthworm counts (biological life and activity)
- Compaction problems
- Presence of rocks
- Previous management practices (crop rotations, tillage)
- Precipitation rates and weather conditions
- Crop prices (or other economic information)
- Land use history (location of old feedlots, fence lines, etc.)
- Management records (planting date, seed variety, pesticide and fertilizer treatments)
- Soil test results (pH, nitrogen, phosphorus, potassium, organic matter)

Interpreting the Spatial Data

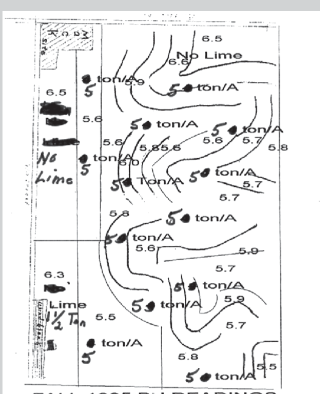
After the observation maps are drawn, the next step is to look for relationships among the landscape features. For example, hard-to-work soils may be consistently associated with low-lying areas, droughty areas may be associated with particular pest pressures, or areas with consistently low yields may appear as wet areas. High phosphorus levels may correlate with the location of an old feedlot. Insect damage may relate to slope. Overlaying the individual transparencies should help identify some patterns. Maps from multiple years of observations may help confirm or refute observed and suspected relationships based on years of farming the land.

A further step is to identify **management zones** and record the results of management decisions on new transparencies. Management zones are areas within a field that are managed differently from other parts of the field. The boundaries of management zones are determined by variations in land characteristics identified on the maps. As described in the section above about scale, a management zone is only useful if the farmer is able to vary management at the scale of variation of the land property. *Farm equipment sets practical constraints on the size and shape of management zones.* Equipment that requires a significant amount of time to change rates is impractical

Another Record Keeping Technique

Rodney Rauk owns a 480-acre farm in Goodhue County in southeastern Minnesota. Rodney has developed a unique record keeping system. Each year he acquires an aerial photograph slide of his farm from the FSA office. On the aerial photograph he looks for anything out of the ordinary, such as light spots, dark spots, or streaks. He can see where the planter missed a row or where an area is wet. He uses this information to locate trouble spots on the farm.

Rodney projects the slide on a wall to which he has taped an 8.5 x 11 sheet of paper. He moves the slide projector until a predetermined portion of his farm covers the sheet completely, but does not spill over. Then he traces significant features, such as terraces, windbreaks, and buildings onto the sheet. This becomes his base map. He makes multiple copies of this map and takes one with him each time he goes to the field. On it, he will record problem areas, crops planted, fertilizer rates, tillage methods, and other management practices and observations. These maps become part of his permanent records.



FALL 1995 PH READINGS AND LIME RECOMMENDATIONS

for fields divided into many management zones. Variable-rate controllers are designed to change rates on-the-go, making fine-scale management zones practical. Smaller equipment also helps in managing at a finer resolution.

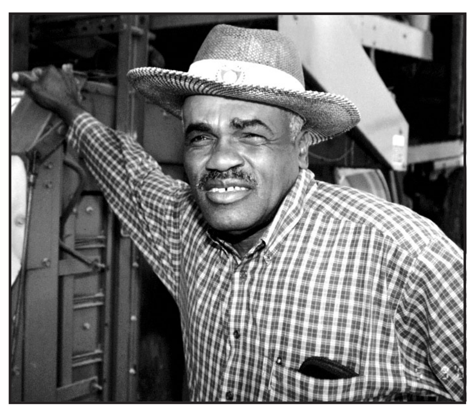
Eventually, it may become clear that more specific quantitative information would be worthwhile to gather. The hand-drawn maps can be used to plan application of a geographic information system (GIS), global positioning system (GPS), and/or other site-specific management technologies. Hand drawn maps are a low cost form of GIS.

Using Interpretations to Make Decisions

Documentation of spatial variability is not particularly useful if it cannot help farmers make better management decisions. Interpreting the maps can help answer questions, such as: Is a significantly lower yield in one part of the field a result of poor drainage, low organic matter, pest pressures, or other factors? Is the variability manageable? Is it cost-effective? The more spatial information available, the more accurate and useful interpretations may be. Since climate interacts with soil and other factors to affect yield response, several years' records of spatial information may be needed to see the full benefit of the interpretation. After identifying soil variation and possible causes, there are two ways to respond: reduce the amount of variation by selectively applying amendments (such as lime to even out the pH across a field) or adapt to the variation (such as by planting different varieties on different parts of the field).

A few examples of site-specific management strategies applied by farmers in different parts of the country based on spatial information gathered follow.

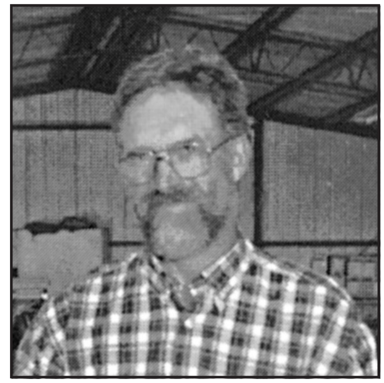
Walter Griffin grows cotton in Bolivar County, Mississippi. He samples his soils regularly and has learned that the ridges require more frequent lime application than the lower areas to maintain healthy soil pH. Applying lime only to the ridges saves time and money. He also experiments with different cotton varieties to determine what grows best in various locations.



Tom Johnson grows soybeans and raises broilers in Worcester County, Maryland. Historically, when soil samples were combined, his entire farm tested high or very high for phosphorus, so he was not able to apply chicken litter anywhere on the farm. Using U.S. Department of Agriculture (USDA) Environmental Quality Improvement Program (EQIP) funds, he had his soils sampled in a 2.5-acre grid pattern. The grid sampling indicated that soil phosphorus concentrations were not high throughout the farm. Mr. Johnson can now apply chicken litter to those areas with low or medium phosphorus concentrations.

Kathy Newkirk and her husband Peter recently purchased an organic farm in Kennebec County, Maine, where they grow a variety of herbs and vegetables. The major limitation of the soils on this farm is poor drainage, which causes some areas to dry out slowly in the spring so they must be planted late. Kathy saves these areas for salad greens and certain herbs that are planted periodically through the growing season. She saves the most productive soils for mixed vegetables and plants squash and certain perennial herbs where soils are less productive, as these crops thrive better under stress. Her complex rotation requires detailed planning. Each year, Kathy makes a detailed map of her planting pattern and schedule. This way she knows where each crop will go before she starts to plant. The plan is flexible and adaptable since timing depends on how soils dry out and warm up in the spring.

Dennis Demmel in Perkins County, Nebraska, grows corn, soybeans, wheat, and sunflowers. He treats his erosion-prone land more carefully than the rest of the farm, planting these areas first to ensure more rapid cover, and tilling less frequently. He performs special tillage operations in weed-infested areas, and applies manure to those areas that are particularly low in organic matter. (Learn more about Dennis in Case Study No. 1.)



Collecting Spatial Information

Sources of Maps

Soil surveys are available for most farmland in the United States. They can be obtained through the local NRCS office or sometimes the Soil and Water Conservation District. Soil surveys provide spatial information about soil properties, such as texture, drainage, seasonal wetness, depth to bedrock, erosivity, and slope.

Aerial photographs are available for most farmland from a variety of sources including county and state planning offices and the local NRCS and FSA offices. The federal photographs are printed at a scale of 8 inches equals 1 mile and are appropriate for field-scale planning. Each photograph usually covers 1 square mile of land. Some photographs available through NRCS may be more than 10 years old, but they still provide valuable spatial information about the farm. Older photographs can also provide excellent historical information. FSA maintains current aerial photographs of farmland as photographic slides, which may be copied at a nominal cost. The slides, however, need to be enlarged at the user's expense. The enlargement changes the original scale, so a new scale needs to be calculated. This can be done by measuring the distance between two known landmarks (such as the farmstead and barn) on the photograph and comparing this distance with the measured distance between them on the ground. It is important to know that scale is not accurate on aerial photographs unless they are **orthophotographs**;

that is, they have been corrected for the distortions caused by camera tilt, curvature of the lens, and topography of the ground. As relief increases, the need for orthophotographs increases.

Digital orthophotographs are orthophotographs that have been digitized into electronic format and corrected for distortions so that distances on the photograph are directly proportional to distances on the ground. Digital orthophotographs can be aligned with other types of digital data to create GIS layers for the farm. Interactive aerial photographs for most of the United States can be accessed from *www.terraserver.com*. This web site also has basic topographic maps and aerial pictures that may be useful.

Infrared photography is a special kind of photography that is sensitive to light wavelengths that are reflected from living organisms, but invisible to the eye. Infrared photography can provide information on the health and vigor of growing crops that standard aerial photography cannot provide. Infrared photographs of local farms are available in a few NRCS offices.

Topographic maps are widely available pieces of information that show the lay of the land. The U.S. Geological Survey (USGS) produces these maps at a variety of scales, and they cover the entire United States. USGS maps of local areas are often sold in bookstores or may be ordered directly from the USGS. For information or ordering assistance call 1-888-ASK-USGS or write to USGS Information Services, Box 25286, Denver, CO 80225. On the Internet, see the USGS web site, *www.usgs.gov.* Topographic maps are sometimes also available through the local Soil and Water Conservation District. These maps provide spatial information on elevation, slope, and aspect (directional exposure).

Other Data

Climate data may be helpful in interpreting variability observed on the farm. The NRCS National Water and Climate Center, in cooperation with Oregon State University, has developed detailed maps of average annual precipitation that may be obtained from each state NRCS office. Maps of average monthly precipitation and temperatures are also available on the Internet at: *http://www.wcc.nrcs.usda.gov/water/climate/prism/prism.html*. These electronic maps require the use of a GIS software package, such as ArcView, ArcInfo or ArcExplorer. However, ArcExplorer can be downloaded from the ESRI web site free of charge (fig. 5).

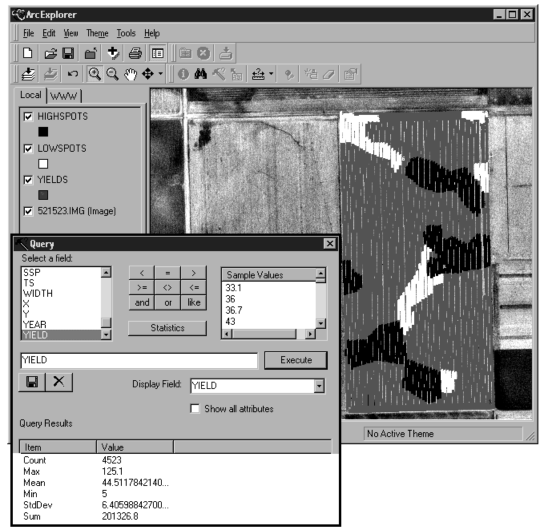


Figure 5. ArcExplorer is a GIS software package that can be downloaded free of charge from the Internet.

Some of the most valuable spatial information is obtained by **direct observation**, personal experience, or oral history. Farmers get to know the land they farm over time. Given the opportunity, they usually pinpoint areas of special concern. These areas may be poorly drained or droughty, consistently produce higher or lower yields than the rest of the farm, warm more slowly in the spring, or be frequently prone to heavy pest pressures. To manage for site-specific differences, it is helpful to record these types of observations continuously along with the specific information used to identify areas of concern (for example, crop yields or soil tests). Soil Quality Health Cards are excellent for directing a farmer through detailed observations of approximately 10 crop and soil parameters (NRCS 2001). Over time, observations can provide a fairly clear picture of the spatial variability that may respond to management.

Estimating Site-specific Yield Without Yield Monitors

One of the most effective ways of evaluating variability is by monitoring differences in yield across a field. Yield differences usually reflect more basic differences in soils, topography, microclimate, or weed competition and can give farmers a good feel for those areas that might respond well to site-specific management. A popular tool of precision farming is the computerized **yield monitor**, a device attached to a combine that estimates yield by measuring the flow rate of the crop being harvested and the area covered by the harvester. When attached to a Global Positioning System (GPS) unit, farmers can map out the variation in yield across a field.

Yield monitors are not the only way to learn how production varies inside fields. With a little care and not much expense, farmers can spot check yields to identify the most productive areas and those needing extra attention. These methods are valid for measuring relative yield—identifying the best areas and the worst areas. They are less useful for estimating actual yield values. Table 1 lists some techniques for estimating yield without yield monitors. Results from these measures can be recorded on transparencies and added to the spatial record keeping kit. Farmers who check site-specific yields soon realize that looks can be deceiving. *Grain yield does not always match how quickly the crop got started in the spring or how tall, dense, or green the crop looks at the end of the season.*

Direct count. Some yield estimates, especially for cereal grains, are based on simple counts of the things that make up yield: plants, pods or ears, and seeds per pod or ear. To estimate corn yields, first count the number of ears in a measured area (for example, a 6-foot row length in a field with 30-inch rows). Then, count the number of rows of kernels on representative ears (possibly every third or fourth ear) and the number of kernels per row on representative rows. Multiply the numbers (number of ears/field area, rows of kernels/ear, and kernels/row of kernels) to get kernels in the field area. Assume yield is proportional to that number.

Kernels for other cereals are more difficult to count. In fields with good stands, the number of spikelets per head of wheat can be used as an indicator of yield potential.

Soybeans are more complicated than the cereals. Pod numbers do not correlate well with yield, so counting pods per plant or in an area is not ideal. Soybean yields are sensitive to the number of seeds per pod and the weight of the filled seed, aspects not captured in pod counts. Instead, weigh the whole plant or use a weigh wagon.

Weights. In some cases estimating yields directly is simpler than relying on counts. Hand-harvest a standard area, bundle the sample, hang it in a barn to dry, and weigh the air-dry samples with a scale. Assume yield is proportional to the weights. Ear samples are convenient for corn. Whole soybean plants and the heads of sorghum and small grains can be clipped with hand shears. Hay can also be harvested in small plots by clipping with hand shears. These observations do not have to interfere with the labor crunch of harvest time. Sampling can be done before the grain is dry enough to harvest, and the weights can be measured in winter after the harvest is finished.

Table 1. Methods for estimating site-specific yield.

Method for Estimating Site-specific Yield	**Common Crops Suited to Yield Estimation Method**					
	Corn	Wheat	Soybean	Sorghum	Small Grain	Hay
Direct seed/spikelet count	X	X				
Whole plant weight			X			
Weigh heads/ears/fruit	X	X		X	X	
Use weigh wagon	X	X	X	X	X	X
Measure distance between bales						

Weigh wagons. In some parts of the country, groups of farmers coordinate the use of weigh wagons to measure combine-harvested yields. If small yield differences are important, weigh wagons become necessary (fig. 6). When a weigh wagon is used, the area harvested must be measured accurately to calculate the yield per acre. Soybean is a good candidate for weigh-wagon yield estimates given the poor relationship between pod counts and yield.

Figure 6. Weigh wagons may be used to measure combine-harvested yields. If small differences in yield are important, weigh wagons become necessary. *(Photo courtesty of University of Nebraska Southeast Research and Extension Center).*

Interpretations. No single method for estimating site-specific yields works in every case. There are always trade-offs. Faster methods may be less precise, but more locations can be checked and observations are more likely to fit into a farmer's work schedule. *Whatever method is selected, make it systematic*. Carefully follow the same procedures at every site so that the estimates of site-specific yields are comparable throughout the field.

Use caution in interpreting yield information. Relative yields are not always consistent across a field from year to year. Yields may be higher than average in one section of the field one year and lower than average the next year. The factors affecting these differences are not always understood, but weather plays a role. Major management decisions should not be based solely on one or two years' yield data. Yield differences are indicative of underlying differences in the site. Determining what those differences are is the challenge the farmer faces. Knowing the cause of the yield variation helps the farmer make decisions regarding what to do about it.

Detailed Soil Sampling

Much information about spatial variability on a farm can be determined and managed by directly observing crop responses in different places on the landscape. Sometimes variability does not seem to relate to landscape position or general soil characteristics. In these cases, a detailed soil sampling procedure may be worth the investment. **Grid soil sampling** is a procedure used to obtain an unbiased assessment of the variability that exists in a field. It involves laying a grid over a field and testing soil samples at the corners or center of each grid cell. The grid spacing may be uniform or may have a range of sizes. The results of the grid soil sampling can be used to create a detailed soil fertility map or series of maps that indicate the variability of measured soil properties throughout the field. Grid soil sampling is fairly expensive, and unless the grids are fine enough, the resulting soil fertility maps may be misleading.

A less expensive method of soil sampling for spatial variability is **directed soil sampling**. Directed soil sampling focuses individual samples in areas that are likely to have different characteristics. For example, areas in which yield is consistently higher or lower than the rest of the field, areas with minor landscape fluctuations, and areas with distinctly different soil types may warrant separate soil samples. Over time, these samples could help the farmer establish management zones within the field. Each management zone must be tested or monitored separately. When sampling an area, producers must be aware of variation within the area they are testing to avoid systematic bias. For example, always sampling in the bottom of the furrow can lead to a result different from sampling the entire area between rows. Farmers avoid this problem by collecting soil from a variety of positions and mixing it well before subsampling and sending it for analysis. Soil pH, organic matter, and phosphorus often vary by depth, so the soil must be sampled to exactly the desired depth to avoid misleading results.

Soil fertility maps correlate with yield to help determine management strategies within a field. However, soil fertility maps do not account for the over-riding effects of weather on yield, and may be misleading if these effects are not recognized. These issues can be addressed by

Figure 7. Regular soil sampling and analysis provide valuable information about the variability on the farm and how it may change over time.

keeping records over several seasons (temporal variability record keeping). What is most important to remember is that the more farmers know about the variability on the lands they farm, the better the management decisions they can make.

Soil Quality Assessments
Soil quality is how well soil performs functions, such as crop production, water retention, or water filtering. It can be assessed using several on-farm techniques including the Soil Quality Test Kit (fig. 8) and the Soil Health Card. The *Guidelines for Soil Quality Assessment* provides help in choosing which methods are most appropriate for assessing soil in a specific situation. All three of these publications are available on the NRCS Soil Quality Institute web site at *www.statlab.iastate.edu/survey/SQI*

On-farm Testing
On-farm testing is an excellent tool for helping farmers determine sources of variation and appropriate management strategies for addressing those sources of variation. On-farm testing will be the topic of a future technical note in this series. Publications on on-farm testing are already available through various sources. A good reference entitled, *How to Conduct Research on Your Farm or Ranch,* is available through the Sustainable Agricultural Network (SAN). SAN is the national outreach arm of the Sustainable Agriculture Research and Education (SARE) program, administered by USDA-CSREES. The publication is also available on the Internet at *www.sare.org/san/htdocs/pubs/*

Figure 8. The soil quality test kit can be used to assess how well a soil performs its intended functions.

Summary

Where farmers apply inputs uniformly across a field, they are using resources inefficiently because not all parts of the field need the same treatment. Farm profitability can be improved by finding ways to reduce these inefficiencies. Precision agriculture, or site-specific farming, has the potential to enhance farm management decisions. While new equipment and technologies are constantly being developed and marketed, their expense may outweigh their benefits for many farmers. Nevertheless, the concepts behind the technologies are appropriate for everyone to consider. The core concepts are identifying and recording manageable spatial variability and using the information to improve farm management. This publication presented methods for applying these concepts without major capital expense. Whether spatial records are kept digitally or by hand, the quality and consistency of those records will determine their usefulness in helping to make good farm management decisions.

The case studies that follow provide further examples of how management based on knowledge of in-field variations benefits farm profit and conservation goals.

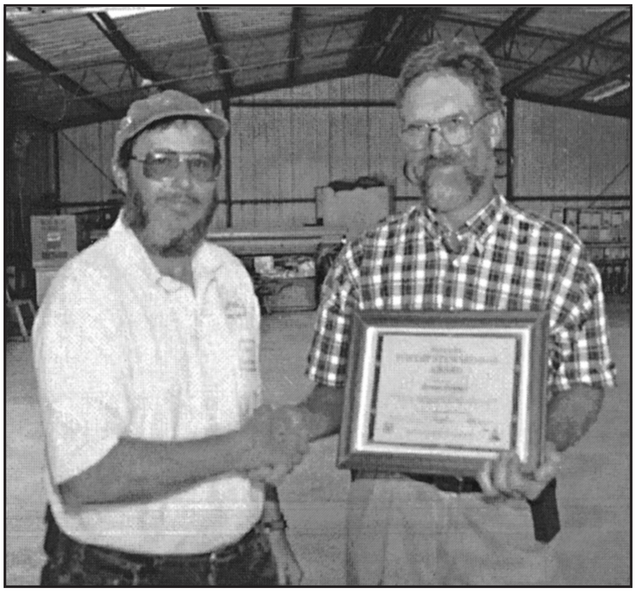
Precision farming includes:

- Assessing land variability
- Documenting and maping the variability
- Interpreting variability across the farmscape
- Estimating yield
- Taking intensive soil samples
- Performing on-farm tests
- Changing management strategies in response to the above factors

Case Studies

Two case studies follow. The first is a farmer who has adopted the concepts and principles of precision agriculture without investing in expensive precision technologies. The second is a farmer who has been working with researchers for the past several years to test a variety of precision technologies. Both farmers believe that knowledge about the spatial variability on their respective farms makes them better managers. Both have ideas to share about how best to use this knowledge.

Dennis Demmel



Dennis Demmel (right) accepts 2001 Forestry Stewardship Award.
(Photo courtesty of Grant Tribune Sentinel).

Location:
Perkins County, Nebraska

Resource Conservationist:
USDA NRCS
Grant Field Office
P.O. Box 40
Grant, NE 69140-0040
Tel: (308) 352-4776 ext. 3
FAX: (308) 352-2262

Acres Farmed:
1,500 (1,250 dryland, 250 irrigated)

Crops:
Soybeans (irrigated)
Winter Wheat
Sunflower
Corn
Legume cover crop

Other Enterprises:
Pastured Poultry

Farmer Objectives:
Develop a farm with good soil fertility and sustainability that will be of interest to a younger person.

Site-specific Farming Practices:
Highly Erodible Land (HEL) Management
Weed Management
Variety Selection
Soil Fertility Management

Transition to High Tech:
Will depend on cost of technologies

Site Description

Dennis Demmel owns or rents approximately 1,500 acres and custom farms another 300 to 400 acres of land in Perkins County, Nebraska. He and his wife, Ruth, moved here 17 years ago. They rent much of their land from her family. The Demmel's are working toward organic certification. The climate in this part of Nebraska is continental with very cold winters and hot summers. The total annual precipitation is about 19 inches with 80 percent falling during the growing season. Some areas of the farm support dryland crops while others are irrigated. The average annual snowfall is 38 inches, but snow cover is quite sporadic. Winds blow from the southeast from June through September and from the northwest from October through May. Average wind speed in the spring is 14 miles per hour, so wind erosion can be a problem in this area if soils are not protected.

Topography on the farm is variable. Soils are nearly level to moderately sloping and range from poorly to somewhat excessively drained. Many of the soils have a calcareous layer 30 to 60 inches below the soil surface. Some of the soils are classified as Highly Erodible Land (HEL).

Site-specific Farming Applications

Dennis' site-specific farming practices have been grouped into five areas:

***1. Highly Erodible Land* (HEL)**. Dennis manages HEL land separately from the rest of his farm. His standard crop rotation on non-HEL ground consists of wheat, corn, sunflowers, and pea-legume/fallow. On HEL, he omits the sunflowers, which produce a limited amount of residue for soil protection. He also tills less often during the fallow year, letting the cover vegetation grow a little longer between tillage operations to help build up residue cover. He plants winter wheat on HEL ground first to ensure an early cover on the most erosive soils. Dennis and his father-in-law have also planted field windbreaks on much of the HEL land to help create a more suitable microclimate for growing crops.

2. Tillage Modification. Ridge till is used extensively for row crops. Dennis uses a sweep plow chisel with 16-inch sweeps or a row crop cultivator to control weeds. This system leaves stubble standing through the winter, which is especially important for trapping snow on the higher elevations. Dennis plants with a wider spacing when drilling wheat on the drought-prone hilltops to create deeper furrows that reduce wind erosion and hold moisture when drilling on the contour. Moisture is always a concern in this part of the country. While he uses tillage to control weeds, his tillage is as shallow as possible to conserve moisture and reduce carbon loss. He has found that keeping a loose mulch cover over the soil helps conserve moisture, but a firm soil base under the thin mulch is needed to cut through residue when planting row crops. Dennis says, "If tillage is deep and the loose mulch cover is thick, it is like trying to cut through a carrot that is sitting on top of soft ice cream." He tries therefore to maintain a compromise between the two extremes of conventional tillage and no-till with herbicides. Herbicides are avoided on the Demmel farm except for spot treatment of Canada thistle.

3. Weed Management. Dennis focuses dryland tillage on the poorly-drained, low-lying soils to combat winter annual weeds. Weeds are also a problem on higher elevations of irrigated fields, where the soil is harder and more prone to drought. Dennis is working to control weeds, particularly Canada thistle (a common rangeland weed), on the hilltops by improving soil fertility. He has tried a number of biological control measures designed for rangeland, but has found them ineffective in cropland.

4. Variety Selection. Dennis plants different wheat varieties in different places on his farm. He plants Arapaho wheat on hilltops. This variety produces significantly more residue than the semi-dwarf varieties planted in the low-lying areas. Hilltops are planted early for earlier ground cover. They are also drilled on the contour for additional conservation purposes.

5. Soil Fertility Management. One of Dennis' goals is to improve soil fertility on the poorer soils, to "level the playing field," so to speak. He has been using a technique called zone fertility management to implement the philosophy of Neal Kinsey. Kinsey's concept, which was furthered by William A. Albrecht of the University of Missouri (Albrecht 1958), is that the balance of soil nutrients in healthy cropland will mimic the balance of nutrients in humans. Zone fertility management involves a modified soil sampling method. Dennis has identified four zones in his irrigated fields that he samples systematically. They are (1) high elevation sand, (2) low ridge, (3) average field, and (4) depressions. He has spot checked the yields in the different zones and has determined that yield does indeed vary with zone. The high ridges tend to be drought-prone. The low ridges, which are more difficult to work than the high ridges, harbor weed problems, and the depressions tend to have poor drainage. Dennis uses USDA soil survey maps and direct observation to identify his zones and preferentially applies nitrogen and compost to the poorer soils. He notes that he has a distinct advantage over farmers who hire custom operators in that he can record his observations as he plants or harvests.

Transition to "High Tech"

Dennis currently owns a computer, but does not use all of its capability. He presently limits its use to word processing and farm accounting. If he were to decide to purchase any of the new precision technology, he would probably purchase a yield monitor to help him more quickly identify problem areas. He would consider purchasing variable rate irrigation technology last, as he feels it is far too costly. He is interested in learning more about infrared sensing as a method of identifying crop stresses before they become apparent to the naked eye. He knows there is variation in all his fields, but only some of it is manageable. That is the variability he wants to focus on for now.

Two keys to the Demmel program of soil improvement are shallow tillage (which requires modified equipment and precision management) and use of legumes in the rotation. As he says, "It's a systems approach here."

Jonathan Quinn

Left to right: Ted Haas, Jonathan Quinn, and Scott Quinn

Location:
Cecil and Kent Counties, Maryland

Resource Conservationist:
Lindsay Tulloch
Cecil County Field Office
105 Chesapeake Blvd, Suite B-3
Elkton, MD 21921
Phone: (410) 398-4411
Fax: (410) 392-6530

Acres Farmed:
1,400

Crops:
Corn
Soybeans
Wheat
Barley

Other Enterprises:
Custom Farming

Farmer Objectives:
Learn everything he can about his farm to make more informed management decisions.

Tools Used in Site-specific Management:
Yield Monitor
GPS
Variable Rate Applicator
Grid Soil Sampling
GIS Assistance
Satellite Imagery

Site-specific Farming Applications:
Soil Fertility Management
Pest Management
Variety Selection
Seeding Rate
Information

Jonathan Quinn manages 1,400 acres of cropland on Maryland's Eastern Shore. His rotation consists of corn, soybeans, wheat, and barley. He has always been progressive. He was one of the first farmers in his area to apply manure to his fields as a source of nutrients and organic matter, rather than disposing of it as a waste product. He was also one of the first to embrace site-specific farming technology.

In 1995 Jonathan teamed up with Ted Haas, regional extension specialist, and Scott Quinn, agricultural consultant currently with Farmsite Technologies LLC (formerly with Royster Clark), to determine just what aspects of site-specific farming technology could be adopted on the Eastern Shore. With help from Extension Agriculture administrators, they obtained a USDA research grant to develop an experimental farm in Kent County where site-specific farming technologies could be tested and demonstrated. Through the grant Jonathan was able to acquire a yield monitor, variable rate applicator, a global positioning system, and a series of detailed grid soil samples and analyses. Royster Clark and the Extension Service have supplied the GIS technology and many hours of consultation. Jonathan has been able to use what he has learned on the experimental farm (called the Wicks Farm) to better manage the farm where he lives. The information he has obtained at the Wicks Farm has convinced him to invest in some of these technologies on his own. He is convinced that this experimental partnership is making him a better farmer.

Site Description

The climate on the Eastern Shore of Maryland is humid continental, with well-defined seasons; however, the climate is strongly moderated by influences from the Chesapeake Bay, and to a lesser extent, the Atlantic Ocean. Because of these influences, the climate in Kent County, which borders the Chesapeake Bay, is milder than that in Cecil County just to the north.

Summer high temperatures average between 85 and 90 degrees Fahrenheit, and winter lows average 22 to 27 degrees Fahrenheit. Rainfall averages about 40 to 45 inches annually and is fairly evenly distributed throughout the year. Average annual snowfall is about 20 inches. Drought can occur in any season although it is most likely to occur during summer. Irrigation is not common, but is occasionally required to obtain maximum yield potential.

Summer thunderstorms are common. Hurricanes affect the area an average of once a year, but tornadoes are rare. Average wind speed is about 10 miles per hour, but wind speeds can reach 50 to 60 miles per hour during severe thunderstorms.

The soils in this part of Maryland are nearly level to gently sloping and are primarily in the Mattapeake or Othello series. Othello soils are generally poorly drained, have moderately slow permeability, a seasonally high water table, and are easily compacted with tillage. The Mattapeake soils, in contrast, are well drained. They have moderately fine-textured topsoil and medium textured subsoil. Mattapeake soils have a high available moisture holding capacity and are well suited to nearly all crops. Both types of soils are acid when not limed. Subtle differences between soils in this area are often difficult to discern with the naked eye.

Site-specific Farming Applications

Soil Fertility. After grid sampling the entire experimental farm and finding the pH to vary widely across the fields, the team decided to demonstrate the benefits of variable-rate lime application. By applying lime at recommended rates where needed, Jonathan was able to “even out” the soil acidity throughout the farm. This improved the efficiency of all other nutrient inputs and enhanced the efficacy of pesticide applications, reducing the amount of pesticide needed. Variable rate liming proved to be a cost-effective application of site-specific farming.

Pest Management. One of the pests Jonathan has been concerned with is *Septoria*, a fungal pest, in wheat. The team has been experimenting with using remote sensing as a preliminary scouting technique for the pest. The results of their experiments have allowed Jonathan to make informed decisions regarding when or if to spray.

Using remote sensing photography coupled with a professional scout, the team was able to detect *Septoria* problems in its early stages. Using the yield monitor, Jonathan was able to determine that spraying for *Septoria* early resulted in an average yield increase of 4 bushels wheat per acre. However, the cost of the remote sensing technology combined with the cost of the fungicide negated the added income realized by the increased yields when wheat was selling at $4 per bushel. When the price of wheat dropped below $4 per bushel, spraying for *Septoria* was not economical. This kind of information has helped Jonathan make better pest management decisions.

The team has also been testing the use of infrared photography as a preliminary indication of spider mites, western corn root worm, and nutrient deficiencies. Currently, scouting is being performed on the ground, and satellite photographs are being used for backup comparisons. The technology is currently not cost-effective, but Jonathan believes that one day satellite photos will be a major tool for pest scouting. He sees a time when scouts will use satellite imagery to target the areas to be scouted on the ground.

Variety Selection. Jonathan uses his yield monitor for on-farm testing to compare the performance of different crop varieties. This helps him determine which varieties to plant the following year. Because he has detailed soils information, he can compare variety performance on different soil types. His results are sometimes surprising. The varieties thought to yield best do not always meet expectations. Using the yield monitor data, Jonathan feels confident that he is selecting the best varieties for his farm.

Seeding Rate. In 1999, the team tested the cost-effectiveness of varying the seeding rate of corn. They found that reducing the seeding rate from 28,000 to 20,000 seeds per acre on the droughtier soils resulted in equal or better yields and lower input costs.

Jonathan feels strongly that the variable rate technology and yield monitor information have made him a better farmer. Not everything he has tried has been cost-effective, but everything he has tried has taught him something more about the farm. He agrees with Ted Haas, who says, “Data gives you better information. Better information gives you better knowledge. Better knowledge helps you make better management decisions, and better management decisions translate into better farm production *leading to greater farm profitability*.”

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Web Resources

Precision Agriculture page at the University of Illinois: *http://www.aces.uiuc.edu/~vo-ag/precise.htm*

NRCS 2001
The Soil Quality Card Design Guide
http://www.Statlab.iastate.edu/SQI/cardguide.html

Glossary Of Precision Agriculture Terms

Accuracy—Agreement between a measurement and the true value.

Aerial photography—Images taken from aircraft or satellites to document variation within fields.

Base map—The standard map on which other sources of information are matched and compared. For agricultural applications, the base map shows field boundaries and key land features.

Contour—A line connecting a set of points, all of which have the same value. Typically, contour lines show elevations above mean sea level of the same value across the landscape. However, contours showing crop yields or soil pH can also be constructed if enough points are measured.

DEM (Digital Elevation Model)—A digital representation of the elevation of locations on the land surface. A DEM is often used in reference to a set of elevation values representing the elevations at points in a rectangular grid on the Earth's surface. Some definitions expand DEM to include any digital representation of the land surface, including Triangular Irregular Networks (TINs) or digital contours.

Differential correction—Method for removing sources of distortion in GPS signals, to improve their accuracy. Requires comparison of the GPS signals to the signals received at the same time at a fixed position. Real-time differential correction requires the GPS unit to receive a signal from the equipment at the fixed position.

Diagnostics—The information and processes used to determine the cause of production problems.

Digital orthophotos—An aerial photograph that has been digitized and corrected for the distortions caused by camera tilt, curvature of the lens, and topography of the ground. Accurate measurements of area and distance are possible on digital orthophotos. Used as a base map for digital soil surveys.

Directed sampling—Collection of soil or plant samples in places of special interest to the farmer. Soil color, elevation, soil classification, and farmer intuition can be used to select the points. Also called smart sampling.

Farmer intuition—A sense for the factors influencing crop yield based on the experience of field work under different weather conditions and on a variety of soils.

Geographic Information Systems (GIS)—System of computer hardware, software, and procedures designed to support the compiling, storing, retrieving, analyzing, and displaying of spatially referenced data for addressing planning and management problems.

Georeference—Data that locates a position relative to the surface of the Earth.

Grid sampling—Collection of soil or plant samples in a rectangular sequence of rows (at the same latitude) and columns (at the same longitude). Represents areas within fields equally.

GPS (Global Positioning System)—A means for measuring georeferences. Ag-oriented GPS units typically process signals from a network of U.S. Defense Department satellites.

Ground truthing—The collection of field data to confirm the results of remote sensing.

Infrared photograph—A photograph taken with infrared film, which responds to wavelengths just beyond the red end of the visible spectrum, such as radiation emitted by a warm body.

Latitude—Degrees, 0 to 90 north or south of the equator to the point of interest.

Longitude—Degrees, 0 to 180 east or west of the prime meridian located on a great circle that passes through Greenwich, England.

Management zone—Region within a field receiving the same combination of inputs. Sample data are often averaged within management zones.

Mapping software—Computer program capable of storing and retrieving spatial data, plotting it on-screen, and printing hard copies.

Oral history—Information passed down from generation to generation by conversation.

Prescription map—A representation of how much amendment should be applied at each position within a field.

Precision—Consistency. Likelihood of getting the same result when a measurement or calculation is repeated.

Projection—The way a three-dimensional object is displayed on the two-dimensional surface of a map. Different projections are used to limit the distortion caused in the process.

Registration—The process of making maps line up.

Remote sensing—Measurements made at a distance.

Resolution—Measure of the smallest things that can be differentiated. Often determined by the number of decimal places recorded.

Scale—(1) For printed maps: The size of something on a map divided by the actual size of the object. Modern soil surveys are done on maps of scale 1:12,000 or 1:24,000. For example, 1 inch on the map with a scale of 1:24,000 would equal 24,000 inches on the ground. The larger the number on the scale, the less detail is shown. (2) For digital maps: The map scale of the original image.

Spatial data—Records that include information on the location and size of the objects in relationship to other things.

TIN (Triangular Irregular Network)—A representation of a geographic surface using continuous, non-overlapping triangles of various sizes and proportions.

UTM (Universal Transverse Mercator)—A map projection in which the Earth is divided into 60 zones, every 6 degrees longitude from 180 °W longitude (Zone 1: 180 to 174 W) to 180 E longitude (Zone 60: 174 to 180 E). Georeferences are measured in meters north of the equator (i.e., northing) and meters east of the central meridian of the zone (i.e., zone 1: 177 W, zone 2: 171 W, … zone 60: 177 E). A "false easting," normally 500,000 m, is added to calculate easting to make all values positive.

Variable rate controller—Device that allows users to change the rate of application on-the-go. Can be attached to a GPS and microprocessor to apply the amendment according to a prescription map. Prescriptions for fertilizer, lime, and seed are the most important.

Yield monitor—A combination of crop flow sensor, crop moisture sensor, ground-speed indicator, and microprocessor-based data logger, to continuously estimate crop yields. Commercial yield monitors can be connected to GPS units, allowing the user to map the yields.

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